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Essentials of Endodontic Microsurgery

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KEYWORDS

- Endodontic microsurgery • Ergonomics • Root end resection
- Root end preparation • Root end filling

In his book *Working in a Small Place* Mark Shelton chronicles the efforts of a young neurosurgeon, Dr Peter Jannetta, to introduce a radically new microsurgical technique for cranial nerve decompression. Pivotal to the technique was the use of the surgical operating microscope (SOM) for precise visualization and manipulation of the delicate structures. What Dr Jannetta discovered was that not only was the use of the SOM in neurosurgery a rare event but also this particular piece of armamentarium was regarded with disdain by the “Grand Old Men” of the profession. Programs were hesitant to implement this technology, and their residents were discouraged in its use because the senior staff members either felt estranged by the unfamiliarity with the SOM, or threatened by its presence. What Dr Jannetta realized was that, rather than trying to convince the grand old men of the merits of the SOM, he would work from within the system, slowly teaching his residents and wait for a new generation, his generation, to assume the role of senior staff members. He is quoted in the book as saying “It takes twenty years for anything new to really catch on, not because it takes that long to convince the establishment, but because it takes that long for there to be a changeover to people who have grown up with the new idea as being accepted.”¹ Today, all residency programs in neurosurgery require proficiency with the SOM and microsurgery.

An interesting parallel is drawn when one examines the progression of the dental operating microscope (DOM) use in dentistry and, specifically, endodontics. Although

Movies can be viewed within this article at <http://www.dental.theclinics.com>, April 2010 issue.

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presented as early as 1986 by Selden,² it was not until the early 1990s that the DOM was introduced to the profession and graduate-level endodontic programs.^{3–6} The usefulness of the DOM in endodontics was viewed with similar skepticism by the senior attendings of most programs for all the same reasons of their counterparts in neurosurgery. However, a concerted effort was made by a few enlightened individuals with foresight enough to recognize the advantages that microscopy could afford, and they lobbied their cause until the late 1990s, when it was mandated that all graduate programs and students demonstrate a proficiency in the use of the DOM. Before 1999, only 52% of the endodontists surveyed reported using the DOM.⁷ Compare that to a more recent survey,⁸ in which the age of the operator was compared with their usage of the DOM and it was found that the younger respondents (35 years old or younger) used the DOM 97% of the time for surgical and nonsurgical treatment. It is clear that the recent graduates are not only more comfortable with its use, but are also more accustomed to rendering treatment with the DOM. What is an interesting coincidence is that endodontics is approaching the 20-year mark of the inception of the DOM into practice; it would seem that Dr Jannetta's prophecies extend to the dental profession as well!

Although the basic principles of endodontic surgery have not been dramatically changed, advances in armamentarium and microtechniques have attempted to keep pace with the demands of today's endodontic microsurgical environment: greater ergonomic flexibility, more efficient preparation and placement of the root end filling (REF), and more biocompatibility of the materials used.

ANESTHESIA AND HEMOSTASIS

These 2 facets are inexorably linked because the effectiveness of the surgeon's administration preoperatively not only influences the comfort of the patient during the procedure but also the control of hemorrhage at the surgical site. Standard protocol is divided into regional and local injections and are as follows:

1. The administration of a long-acting anesthetic agent such as bupivacaine (Marcaine) as a block technique to obtain a sustained level of anesthesia beyond the duration of the surgery. For posterior surgeries this entails, for maxillary sites, a posterior superior and middle superior alveolar block; for posterior mandibular sites, an inferior alveolar nerve block supplemented with a mental nerve trunk block. Maxillary anterior teeth are blocked using bilateral anterior superior alveolar or infraorbital injections, while mandibular anterior teeth receive bilateral mental nerve blocks. All of these can be supplemented, as need be, with corresponding palatal or lingual infiltrations of the same anesthetic.

In studies examining the effectiveness of lidocaine versus bupivacaine, it was shown that lidocaine was faster in onset of lip numbness while bupivacaine resulted in longer duration.⁹ However, Gordon and colleagues¹⁰ have shown that administration of bupivacaine following surgical extractions resulted in decreased pain for longer periods of time. By minimizing the peripheral barrage of peripheral nociceptive neurons, it reduced the development of central sensitization, thought to mediate partially the central component of allodynia and hyperalgesia. This postoperative effect can be further enhanced by the preoperative administration of a nonsteroidal anti-inflammatory drug, resulting in statistically less postoperative discomfort and delay of onset of pain.^{11,12} This peripheral block should be allowed to take effect (8–10 minutes) and signs of adequate anesthesia noted before the next phase.

2. Once regional anesthesia has been achieved, then a local infiltration of lidocaine 1:50,000 epinephrine is injected over the intended flap extent, concentrating the bulk of the infiltration over the surgical site. The injection speed is slow and steady (1–2 min/mL), allowing time for diffusion of the fluid and avoiding the formation of a bolus accumulating in the submucosa.¹³ Done correctly, blanching will be evident in the surrounding tissues, spreading throughout the flap and its perimeter. Care should be taken to avoid injecting into skeletal muscle. Doing so will activate the β -adrenergic receptors, triggering vasodilation instead of constriction, causing undue hemorrhage on flap reflection and subsequent limited visibility of the surgical site.^{13,14}

The outlined protocol is, of course, predicated on the systemic health of the patient and their ability to tolerate not only the surgical stress but also the cardiovascular impact of the epinephrine in the selected anesthetic. Even in healthy patients a transient tachycardia of short duration is not uncommon, but is usually well tolerated if the patient has been forewarned. However, in cases where underlying cardiovascular diseases such as uncontrolled hypertension or history of recent cardiac surgery place these patients at a higher risk, the surgeon would be prudent to consult with their physician before the procedure.

FLAP DESIGN

There are 3 basic flap designs; 2 are traditional mainstays (Triangular, Ochsenbein-Luebke) and the third a variation of a periodontal surgical incision, the papilla-base flap.

The triangular flap design entails a full sulcular incision at least one tooth mesial and distal of the intended surgical field. The blade tip is in contact with the crest of alveolar bone throughout the incision, severing the periosteum, and carried through the sulcus and into each interdental papilla. As each papilla is incised, it can be gently reflected using the scalpel blade to ensure that a complete cut has been made. A vertical releasing incision is then made, originating at the line angle of the most anterior tooth of the flap, and drawn apically parallel to the long axis of the adjacent roots (**Fig. 1**).



Fig. 1. Triangular (sulcular) flap. The solid red line indicates the sulcular incision from the mesial of tooth #12 to the distal of tooth #15; the dotted line represents the vertical releasing incision parallel to the root of tooth #11. Note the swelling in the mucobuccal fold near the MB apex of tooth #14.

The soft tissue of the flap is then reflected, starting in the vertical releasing incision and proceeding coronally/distally/apically, undermining and releasing the periosteum until full reflection is achieved and the surgical site is uncovered.

The Ochsenbein-Luebke flap was the design of choice in the maxillary anterior when there were concerns about exposure of crown margins or gingival recession following apical surgery (**Fig. 2**). This flap requires that the incision be contained within the attached gingiva, with at least 2 mm between the depth of the sulcus and the incision line. The band of attached gingiva should also be wide enough so that the incision line does not cross the mucogingival junction into the alveolar mucosa. It is imperative that the sulcus depths be mapped, and there are specific instruments made for this purpose called pocket markers, designed like college pliers, with one jaw configured like a periodontal probe and the other having a small “tooth” or projection on the tissue side of the jaw. These instruments are available in left- and right-side models to allow for correct orientation and adaptation to the tooth. The periodontal jaw is placed against the facial surface of the crown of each tooth, inserted to the depth of the facial sulcus at 3 points, and the handles are gently squeezed to bring the pointed end of the opposite jaw into contact with the facial gingival; this creates a series of bleeding points apical to each crown, representative of the depth of each individual sulcus. The incision is made 2 to 3 mm apical to these bleeding points, in a scalloped fashion to mimic the contour of the respective gingival crests. The incision is carried at least 1 to 2 teeth mesial and distal to the intended surgical site, with a vertical releasing incision terminating at both ends. The flap is reflected as with the triangular design, starting at one end of the incision and progressing to the opposite side. Although chosen to reduce the potential for exposed crown margins, this design is contraindicated in cases where a large apical lesion is present or there is an inadequate band of attached gingiva.^{15–20}

The papilla-base flap could be best termed a hybrid variation of a full sulcular and split-thickness incisions, and has been suggested to prevent the gingival recession seen with the aforementioned 2 flap designs.²¹ This flap consists of 2 vertical releasing incisions, connected by intrasulcular incisions in the cervical areas of the planned reflection concomitant with the papilla-based split-thickness variation. The split-thickness incision is accomplished in 2 steps: the first is a shallow cut, meant to sever the

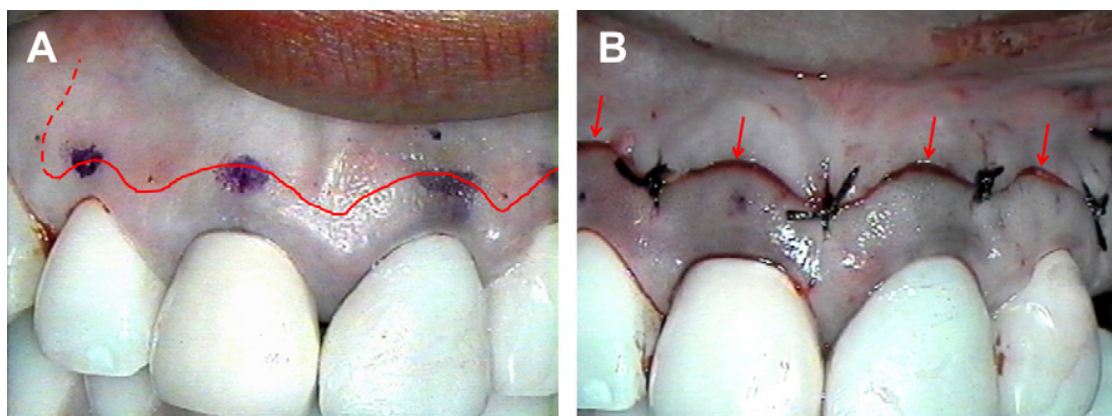


Fig. 2. (A) Ochsenbein-Luebke flap. The solid red line is the scalloped incision in the attached gingiva. The purple dots, made with a Gentian Violet stick, denote the probing depth plus 2 mm at the facial surface of each tooth in the proposed flap. The incision connects these dots together as one line, with vertical releasing incisions (*dotted lines*) at the terminal ends of the flap. (B) Ochsenbein-Luebke flap. The suturing of the coapted “points” of the flap correctly readapt the tissues. More sutures will be added to secure the flap (*arrows*).

epithelium and connective tissue to a depth of 1.5 mm from the surface of the gingiva, subscribing a curved line, perpendicular to the gingival margin, and connecting one side of the papilla to the other. The second cut is more vertical in nature, tracing the original incision but deep enough to contact the alveolar bone margin (**Fig. 3**). This cut will produce a split-thickness flap at the apical third of the base of the papilla.

This split-thickness incision is joined by the intrasulcular cut(s) at the cervical margin, completing the release of the marginal gingival complex. The intended flap is then reflected as a full-thickness mucoperiosteal event, apically positioned as dictated by the intended operative site. The one crucial caveat is the choice of scalpel blade; it should not exceed 2.5 mm in width, to allow for the delicate course of the incision and minimize inadvertent overcutting of the tissue. Although very predictable in terms of minimizing soft tissue recession, this is a very challenging flap design to execute and, if the tissues are mishandled, primary coaptation of the epithelial margins will be compromised; necrosis of the affected sections will occur and lead to formation of a surgical scar.²² Also incumbent in this flap design is the size of the sutures used in closure; 7-0 to 8-0 polypropylene monofilament, at least 2 placed per papilla.

ERGONOMICS AND POSITIONING (PATIENT/SURGEON)

One of the most frustrating aspects of microscopic surgery is the correct positioning of the DOM relative to the patient and operative field. Indeed, a recent survey indicated almost 77% of those responding claimed some difficulty in access and visualization using the operating microscope.²³ Improper positional technique has long been recognized in the medical field, and guidelines to enhance performance and limit fatigue have been presented.^{24,25} In endodontic surgery, the position of the patient is not as important as the position of the root apex and the immediate surgical field. This orientation forms the foundation on which the remainder of the microsurgical procedures is based. To begin, the patient is positioned in a supine to slightly Trendelenberg attitude so that the surgical osteotomy site is most superior in the operating field. This position can vary from the patient simply turning their head to actually laying on their side. The patient can then be stabilized for comfort in this new position using rolled-up surgical towels, “donut” style headrests, or memory foam pillows. The

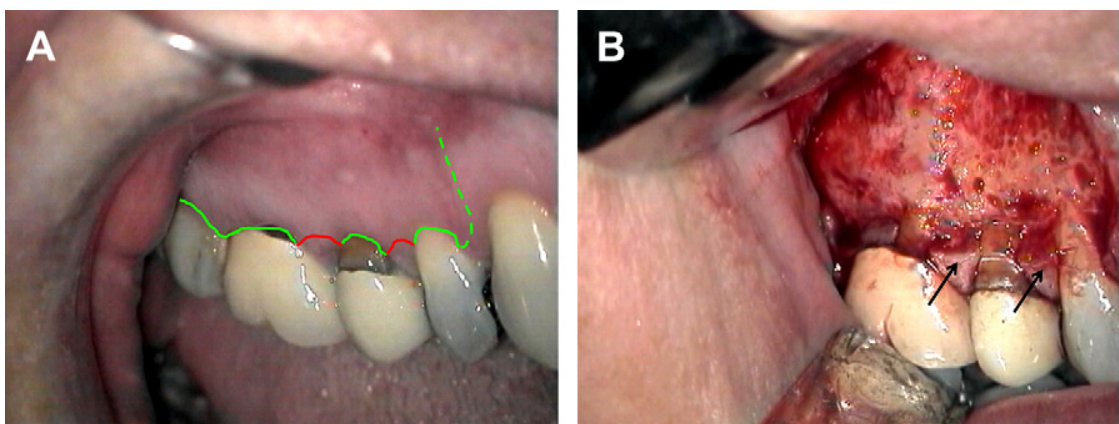


Fig. 3. (A) Papilla-based flap. The green lines denote the full sulcular portion of the incision around the cervical of each tooth, the red lines are the split-thickness incisions for the papillas involved, and the dotted green line is the vertical releasing incision. Note from the text that the papilla incisions are made with 2 different angles and depths. (B) Papilla-based flap reflection. The arrows point to the split-thickness reflection of each papilla. Note the long tissue bed of each papilla, especially between the 2 premolars.

surgeon then takes position at the head of the patient, the 11 to 12 O'clock orientation. The operator's chair height is adjusted so that the angle formed between the thigh and lower part of the foot is a minimum of 90° , and the spine is comfortably straight. The patient's chair is then raised or lowered so that the surgeon can maintain his or her elbows close to his body, passively bent at a neutral 90° . There are several companies that manufacture surgeon's chairs that have elbow rests incorporated into them, affording support of the forearms and elbows. Once positioned, the surgeon's arms and hands should not deviate from the core-centric position; this affords the greatest dexterity and precise micro-control, while limiting fatigue and strain trembling.^{26,27} The microscope is last positioned with the line of sight axis perpendicular to the soft tissue field of the intended flap, and the binocular eyepieces adjusted to a comfortable height relative to the operator.

The selected flap design is then incised, the soft tissue reflected, and the retractor(s) stabilized on the cortical plate. The retractors must be in contact with the bone to avoid inadvertent impingement of the reflected soft tissue or other vital structures such as the mental nerve. The retractors must also be positioned at some distance from the surgical site to afford access for visualization and manipulation of the instruments. However, the extent of the reflection is not as broad as with other oral surgical procedures; rather, the reflection forms a narrow corridor bordered by the edges of the flap. This corridor not only minimizes the trauma to the soft tissues but desiccation of the cortical plate as well. This retraction can be augmented by the assistant using a second retraction instrument such as a Seldin or Pritchard style periosteal elevator to gently redirect a lip or section of the flap that has prolapsed into the field, especially during the osteotomy and root end resection phases of the procedure. Once retraction is complete and stable, the patient is readjusted so that the cortical plate/tooth long axis of the surgical site is parallel to the floor and most superior in the field (**Fig. 4**).

ERGONOMICS AND POSITIONING (PATIENT/SURGEON/DOM): SITE SPECIFIC

Although there is no one correct way to position the microscope relative to the field, an excellent guide would be to visualize what a direct line of sight to the field would be,

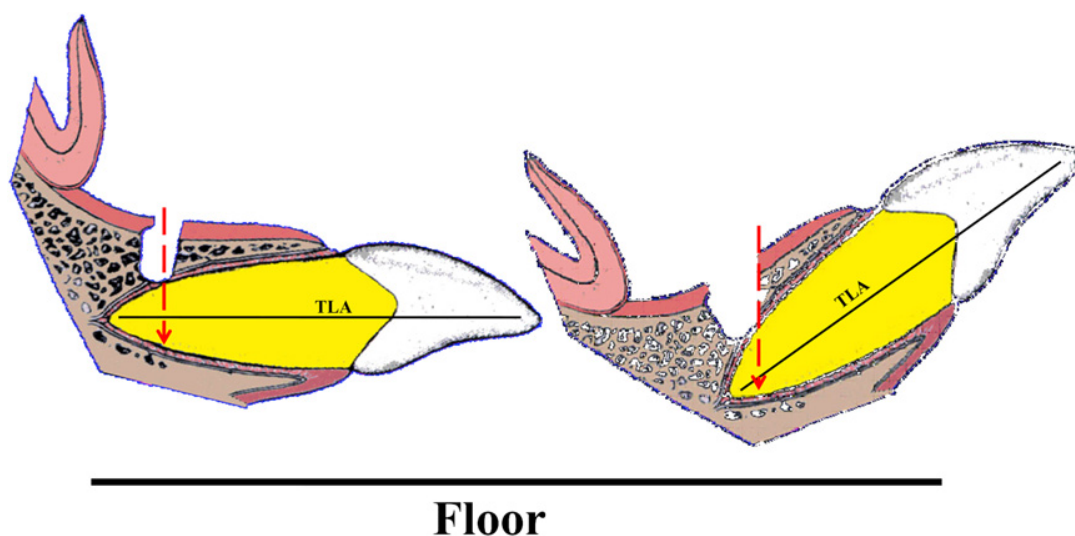


Fig. 4. The correct positioning (*left*) for the tooth long axis relative to the floor on the left. Positioning in this manner allows for the resection to be "gravity driven," dropping straight down toward the floor, making a right angle cut with regard to the facial-palatal direction. On the right, because the angle is incorrect, the osteotomy is larger and the resection is angled from facial to palatal.

then position the line of sight of the microscope along that imaginary line. Inclined optics allow for the microscope to assume different vertical attitudes relative to 90° , and a shift of as little as 20° in either direction will enable the surgeon to look past the head of the handpiece to the end of a burr, or use direct vision to examine a resected root end. It is also imperative to have the microscope visual axis (MVA) parallel to the root long axis (RLA) at the selected resection level; if the observation position is skewed off-angle, the resection will mimic that angle (**Fig. 5**). This section explains the basics of positioning for the microscope; more details concerning the actual root end procedures follow in later sections. For the 4 major quadrants, the respective position guidelines are presented.

MAXILLARY ANTERIOR

The head of the microscope is tilted slightly off from direct vertical, angling from the crown of the tooth toward the apex (**Fig. 6**). This angle will alleviate the superimposition effect of the head of the handpiece; bring the tip of the selected burr into view. Decortication of the intended apical site, if not already exposed by pathologic fenestration, is affected by a small round bur (#2–4) or other specialized bone bur (Lindeman Bone Bur). Care should be taken not to unintentionally gouge the selected root surface during this discovery phase. Use of a nonaerosol producing handpiece, such as an

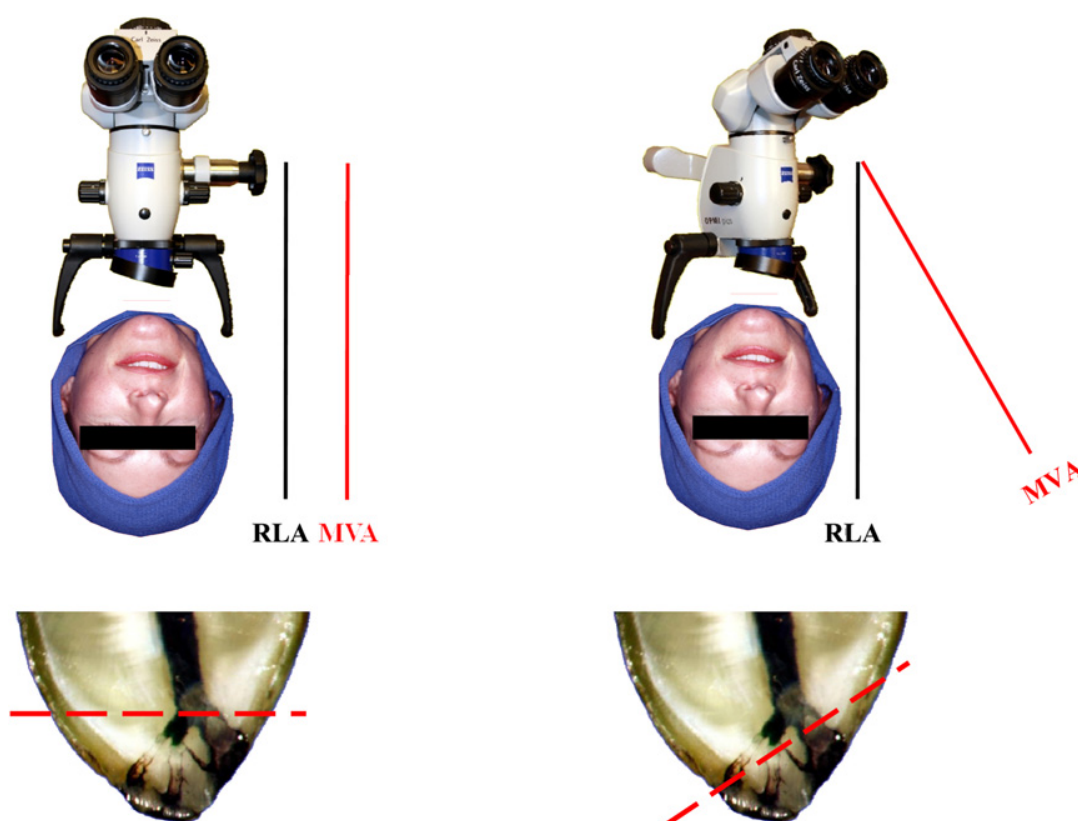


Fig. 5. The relationship of the root long axis (RLA) and the microscope visual axis (MVA). If the microscope and, by extension, the surgeon are positioned in the same line as the long axis of the root at the selected resection site, then the line of resection will be parallel to the surgeon's chest, an ergonomically reproducible path. This positioning will ensure the correct mesial-distal angulation. When a disparity exists, as shown on the right, the surgeon is guided by their body position and line of sight, not the position of the root tip, and an angled resection is made.

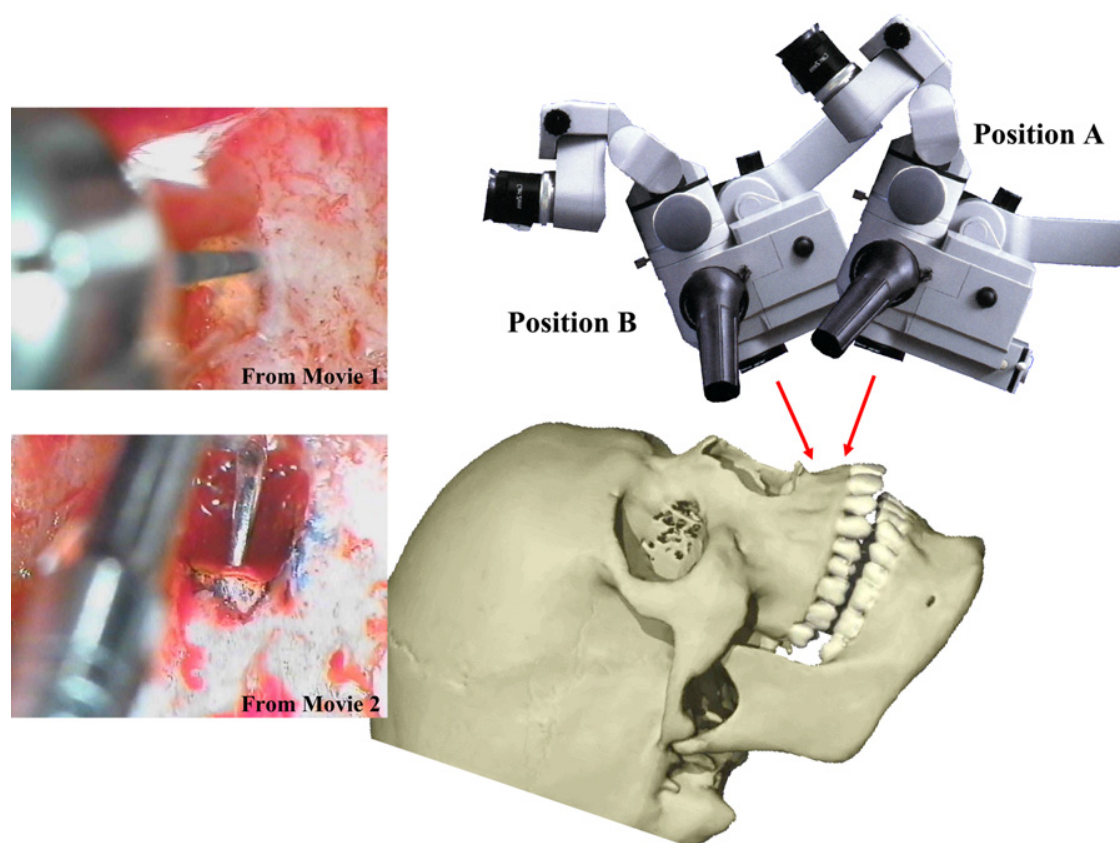


Fig. 6. The correct inclination of the microscope and patient for maxillary anterior surgery. Position A and [Movie 1](#) are for the resection; position B and [Movie 2](#) are for the inspection, root end preparation (REP), and root end filling (REF).

Impact Air (Palisades Dental, Englewood, NJ, USA) will reduce the amount of occult spray in the field and improve visibility without compromising cooling of the bur and bone. Following identification of the selected apex, the osteotomy is enlarged to enable curettage of any lesion present and isolate the root tip from the surrounding surgical crypt. How large an osteotomy should be is predicated on the native size of the lesion, adequate access for the armamentarium, and proximity to vital structure such as the mental nerve, mandibular canal, or maxillary sinus. In a phrase: it should be as small as possible but as large as practical.

Once the root tip is isolated, the surgeon and DOM are repositioned so that they are parallel to the long axis of the root at the selected level of the resection, *not the long axis of the tooth*, and the coronal-apical inclination is reestablished. With the direct line of sight to the bur tip restored, the root end is resected ([Movie 1](#), available along with all other movies cited here in the on-line version of this article at: <http://www.dental.theclinics.com>). Once resection is complete, the microscope is then angled from apex to crown to allow for inspection of the resected root surface with direct vision ([Movie 2](#)). The angle will, of course, depend on the extent and quality of the retraction. Following the resection, the operator will be using micromirrors to more accurately assess the accuracy and completeness of the resected surface. This same angle will also be used to visualize the root end preparation (see [Movie 2](#)).

MANDIBULAR ANTERIOR

The positioning is relatively the same, with a few notable exceptions:

- (a) Positioning of the cortical plate parallel to the floor may not be possible; this should be taken into account during the root end resection and preparation phases. In

many instances, rather than recline the patient to an uncomfortable angle, it may be enough to have them elevate their chin slightly to affect this parallel position (**Fig. 7**) (**Movies 3 and 4**).

- (b) The second angle, coming from the apex to the crown, again may be compromised by the limitations of the reflection and the angle of the patient, but the solution may again be as simple as having the patient elevate the chin for a short period of time to enable the correct line of sight.

MAXILLARY AND MANDIBULAR POSTERIOR

The limiting factor here is the ability of the patient to present the cortical plate parallel to the floor. Using rolled surgical towels or pillows to prop the back of the patient will allow them to comfortably lie on their side in the dental chair, affording a more favorable attitude to the surgical site. An anesthesiologist's "donut" or small pillow can also be placed under the patient's head to gently cushion it in this new position. Failure to achieve this presentation of the surgical field often results in a misdirected "tunneling" of the osteotomy, with the potential for inadvertently damaging adjacent roots or structures (**Fig. 8**). Also, retraction in the most posterior of sites is inhibited by the xygoma or external oblique ridge, and may require repositioning of the retractor(s). Otherwise, the previous rules of positioning of the microscope hold true with respect to the osteotomy, root end resection/inspection, and preparation (**Figs. 9 and 10**) (**Movies 5–8**).

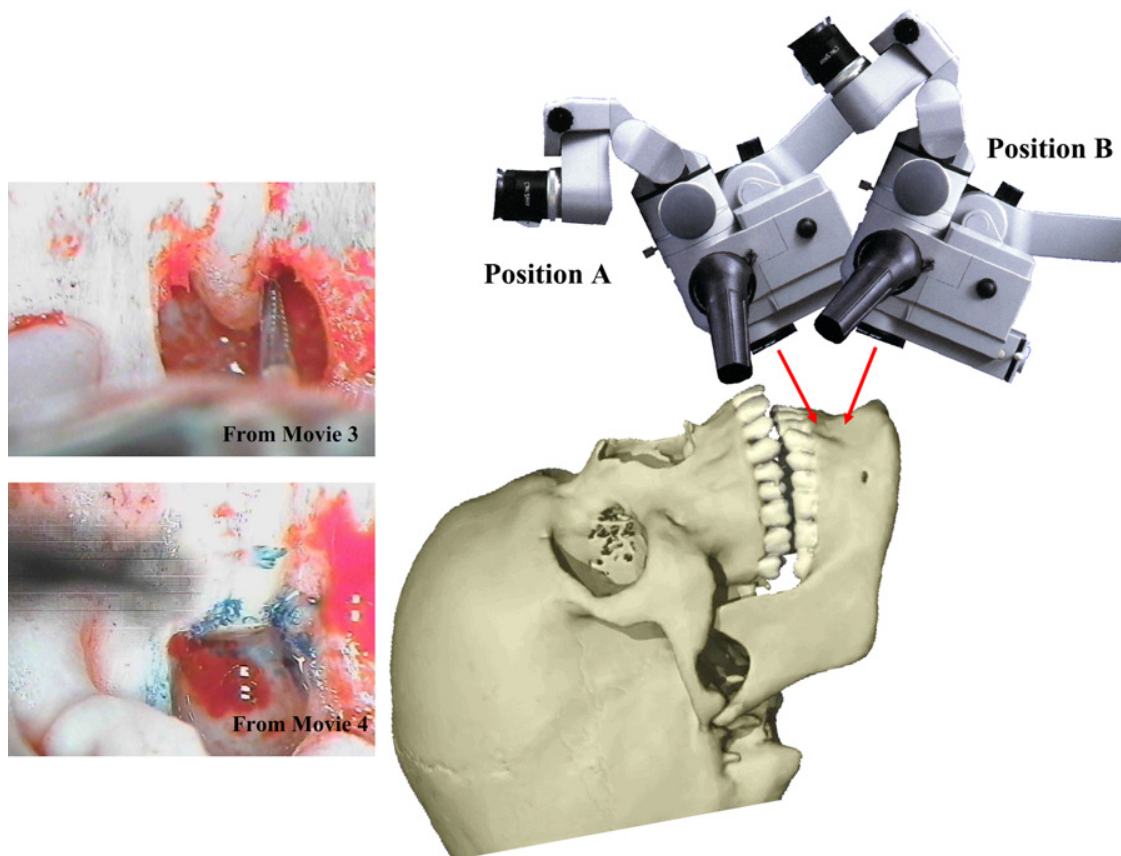


Fig. 7. The correct inclination of the microscope and patient for the mandibular anterior surgery. Position A and **Movie 3** are for the resection; position B and **Movie 4** are for the inspection, REP, and REF.

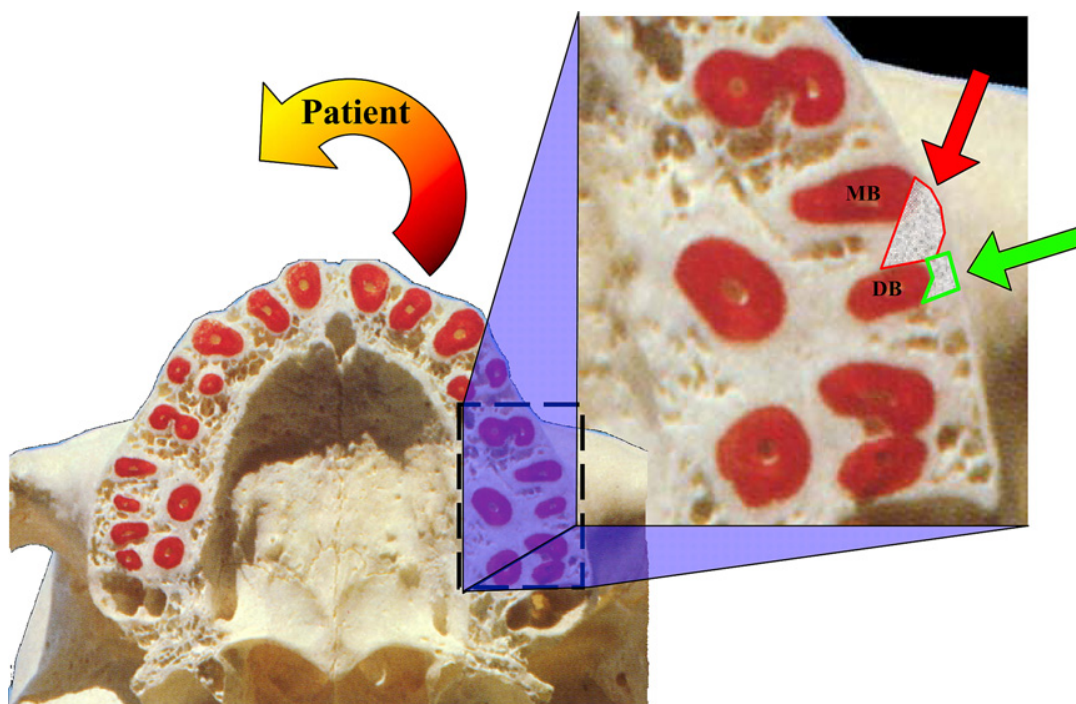


Fig. 8. The magnified area of root apices teeth #13, #14, and #15 shows the correct osteotomy approach (*green arrow*) for the distobuccal root of tooth #14. However, if the patient is facing straight forward, the field of view is distorted at higher magnification, and the approach angle is often too far mesial, resulting in a grazing or gouging of the MB root (*red arrow*). Turning the patient so that the cortical plate of the site is superior in the field alleviates this difficulty.

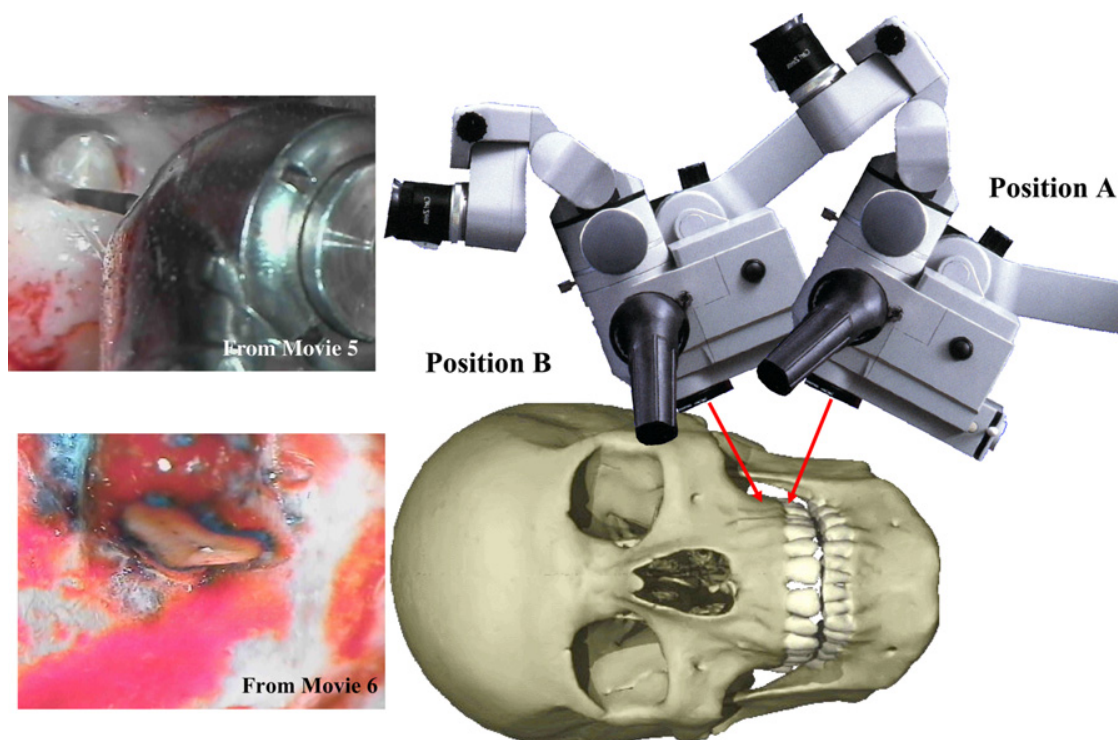


Fig. 9. The correct inclination of the microscope and patient for the maxillary posterior surgery. Position A and [Movie 5](#) are for the resection; position B and [Movie 6](#) are for the inspection, REP, and REF. Note the bow-tie effect on the resected root surface of this MB root.

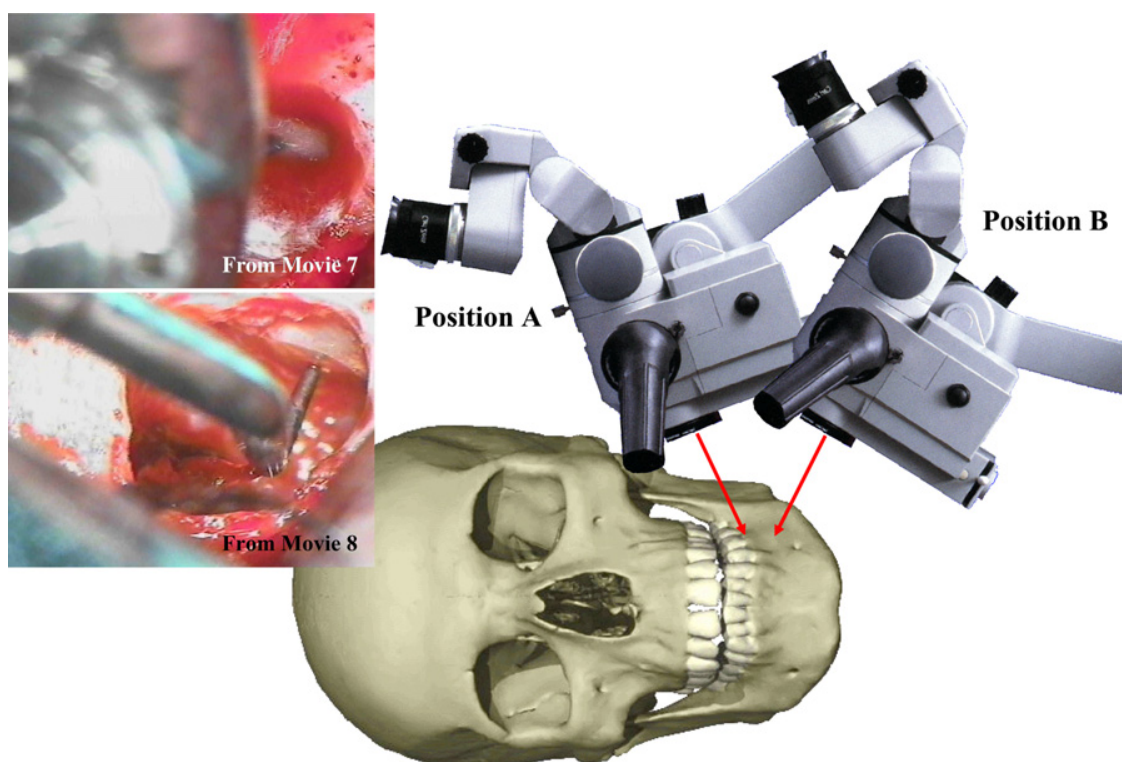


Fig. 10. The correct inclination of the microscope and patient for the mandibular posterior surgery. Position A and [Movie 7](#) are for the resection; position B and [Movie 8](#) are for the inspection, REP, and REF. Note the harvesting of the root apex after resection, and the 2 canals it demonstrates (one filled, one uninstrumented/filled).

ROOT END RESECTION

This phase is perhaps the most pivotal of the surgical procedure, as errors here are magnified with respect to the subsequent root end preparation and successful sealing of the apical extent of the root canal system. The carpenters' axiom of "measure twice, cut once" has great significance, as root structure cannot be replaced once it has been removed, so careful consideration must be given to the length and angle of the resection process.

LENGTH

First and foremost are the restorative implications of the resection with regard to crown-root ratio. There are histologic guidelines for how much of the root end should be removed but if, in doing so, the integrity and stability of the remaining tooth is compromised, alternative treatment options should be explored. If there is sufficient root length in sound bone, then the amount of root apex that is removed is dictated by the prevalence and distribution of the apical ramifications the surgeon hopes to eliminate. As the accompanying diagram shows ([Fig. 11](#)), a resection level of 3 mm from the anatomic apex will eliminate 93% of lateral canals and 98% of any other ramifications such as deltas, fins, and so forth.²⁸ Coupled with a root end preparation depth of 3 mm, 6 mm of infectious etiology in the canal space will have been effectively treated. There are, however, 2 notable exceptions to this rule. First, if the level of resection is such that it leaves a root geometry that is significantly curved at that level, then the root end preparation will be compromised ([Fig. 12](#)). The preparation tips, by design, are 3 mm long, and are not designed to follow curves like a root canal file.

	1 millimeter	2 millimeters	3 millimeters
Apical Ramifications	52%	78%	98%
Lateral canals	40%	86%	93%

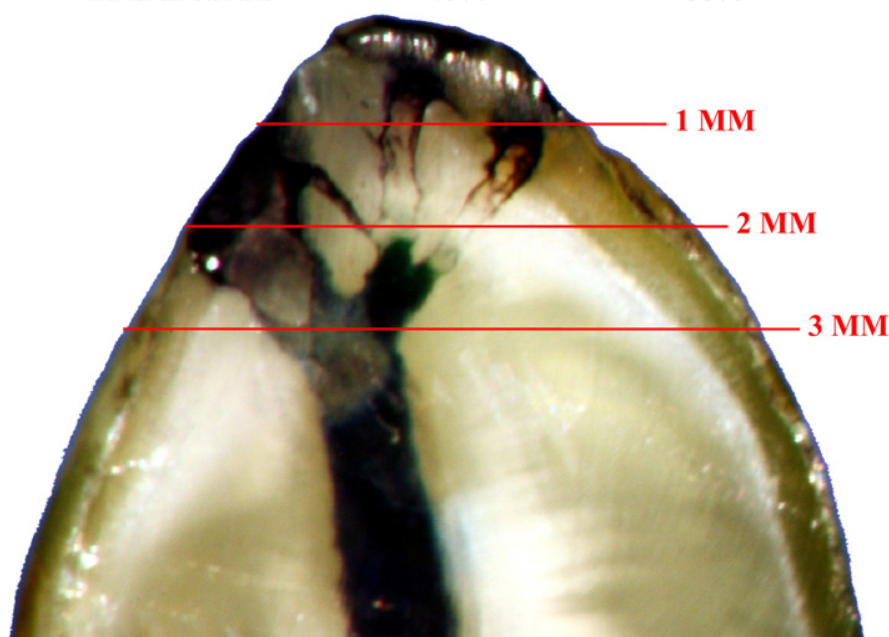


Fig. 11. The relationship of resection level and canal ramifications eliminated in this canine apex. (Data from Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. J Endod 2006;32:601–23.)

Hence, the preparation will be shallower than required because of the tip's impact on the curve or, if forced longer, can in fact perforate the external root surface. This situation can be remedied by increasing the length of the resection past the curve, provided the overall length of the remaining portion of the root does not compromise the crown-root ratio.

The other exception occurs when the root in question has undergone a resorptive process, and is shorter than normal. In this instance, part of that ideal 3-mm length



Fig. 12. The preoperative radiograph of tooth #3 demonstrates the dissimilar curves of the roots, and the correspondingly different angles of resection for each root apex. Note that the resection of the MB apex is slightly shorter so as not to impact the REP into the curve. The postoperative radiograph shows the REF to be well centered and to the correct depth.

has been eliminated involuntarily. Comparison of the root length of the contralateral tooth can assist in determining how much more of the apex needs to be removed, if any. At the very least, the resorbed root apex would likely need to be flattened somewhat to allow for efficient root end preparation and filling/finishing.

ANGLE

Before the introduction of the microscope, resected root ends were routinely beveled to enable the surgeon to visualize the resected surface(s). It was not uncommon for bevels of 30° , 45° , or even greater to be placed because of “convenience.” This beveling was most often rendered by with a #4 to #6 round burr attached to a large, straight nose cone handpiece, such as a Stryker, or with a fissure burr in a conventional slow-speed handpiece. This severe angle contributed to gross apical leakage and often failure of the apical surgery. In 1989, Tidmarsh and Arrowsmith²⁹ examined the implications of the beveled resection (45° – 60°) with regard to dentinal tubule concentration in young and old teeth, and the depth of the effective retrograde seal. These investigators concluded that the potential for leakage was greatest when the bevel was steep and the retrograde filling did not extend deeper than the coronal aspect of the beveled surface. This concept was elaborated upon with the work of Gilheany and colleagues 1994.³⁰ Twenty-seven single-rooted teeth were selected and their root apices were resected at 0° , 30° , and 45° . Apical preparations were created and sequentially filled with a glass ionomer (Ketac Silver). The apical microleakage and dentin permeability were measured by observing and quantifying the fluid flow in a hydraulic conductance apparatus as described by Derkson and colleagues in 1986.³¹ Gilheaney and colleagues concluded that: (1) the amount of leakage increased as the slope of the bevel increased; (2) increasing the depth of the retrograde filling decreased the microleakage; and (3) optimum/minimum depths for the retrogrades were as follows: $0^\circ = 1$ mm, $30^\circ = 2.1$ mm, $45^\circ = 2.5$ mm (**Fig. 13**).

Bur selection for the root apex removal is almost a matter of personal choice. However, here are some guidelines based on the literature^{32–34}.

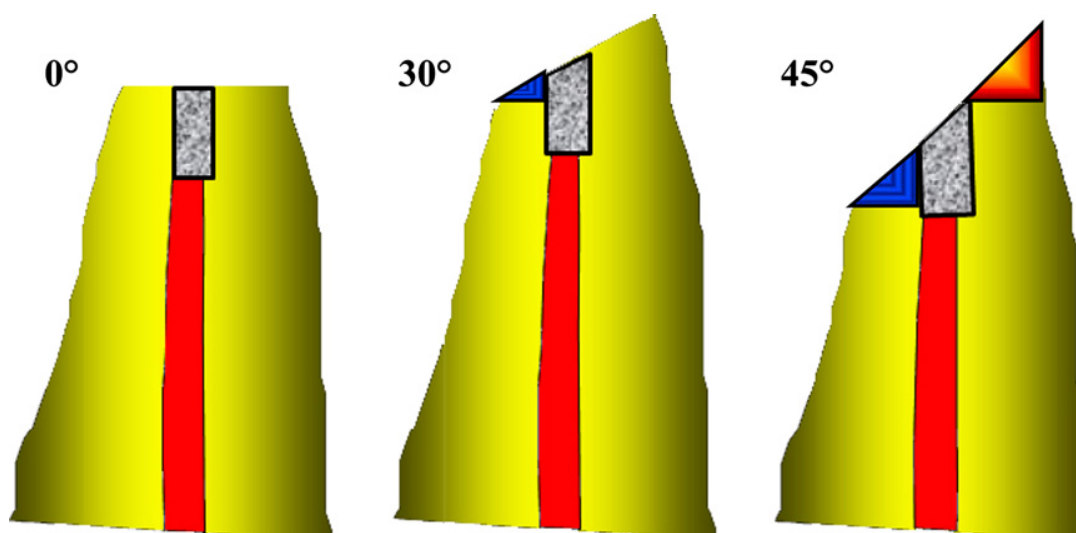


Fig. 13. The impact of different bevel angles, and the amount of lateral leakage through the exposed dentinal tubules to the REF (*blue triangles*). The red triangle in the 45° bevel would represent contaminated tubules left after such a resection in an infected root apex. (Data from Gilheany PA, Figdor D, Tyas MJ. Apical dentin permeability and microleakage associated with root end resection and retrograde filling. J Endod 1994;20:22–6.)

- (a) Straight or tapered carbide fissure configuration, long enough to span the depth of the apex, is advised. If a tapered fissure is chosen, the angle created by the taper should be taken into account during the resection to maintain as close of a 0° bevel as possible.
- (b) Avoid coarse diamond or crosscut fissure configurations as these create surface roughness and irregularities, making it difficult to finish the REF properly.
- (c) Use of the bur in a high-speed handpiece with copious coolant is advised. It is also recommended that this coolant stream not be air driven, as this could potentially induce an air embolism effect in the soft tissues of the surgical field. An example of such a handpiece is the Impact Air, available with or without fiber optic capability.

The technique of the resection is not the “chainsaw” cutting of a tree trunk, but rather akin to the slicing of a piece of bread. In the former action, the coolant would fail to effectively reach the interface of the bur and tooth surface being cut, allowing for the dentinal surface to become overheated and burned. By using the tip of the bur and making progressively deeper passes across the root tip surface, not only will the coolant flush and cool the resection cut but also the first few passes will create a “guide slot” in the root. If any adjustments to length or angle are required, they are easily corrected at this time without undue, and irreversible, damage to the root. This guide slot also serves as a “pilot reference” to maintain the correct angle throughout the resection. Some operators prefer to shave the root end rather than resect it. The author feels that this has the potential to cloud the issue of how much has really been removed, and the shaving of an infected root end disperses just that much more pathogenic material into the surrounding crypt.

Once the apex (ices) has been removed, the first observation made should be of the resected tip cut surface (**Fig. 14**). This view will very often mirror the cut surface of the remaining root, offering a preview of what the surgeon is to expect in terms of number of canals, filled or unfilled, isthmuses, fractures, and so forth. Such observations can also reveal the smoothness of the cut, and whether the resection was complete; a jagged edge along the perimeter of the root usually indicates that portion of the root being broken off, rather than cut cleanly. The situation is confirmed clinically by examining the remaining root surface, either directly or in a micromirror.

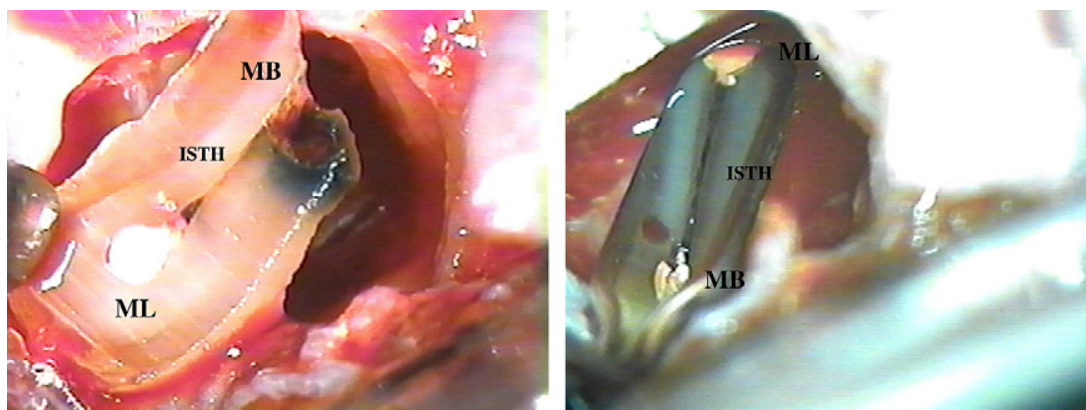


Fig. 14. The picture on the left shows a root tip harvested after resection in this surgical re-treatment. The black stain near the MB canal is from the amalgam retrograde. Note the long isthmus seen in this tip; it is the mirror image of what can be expected when the resected surface of the root is viewed. The picture on the right is the micromirror view of the resected surface; an exact replica of the observation made from the harvested root tip.

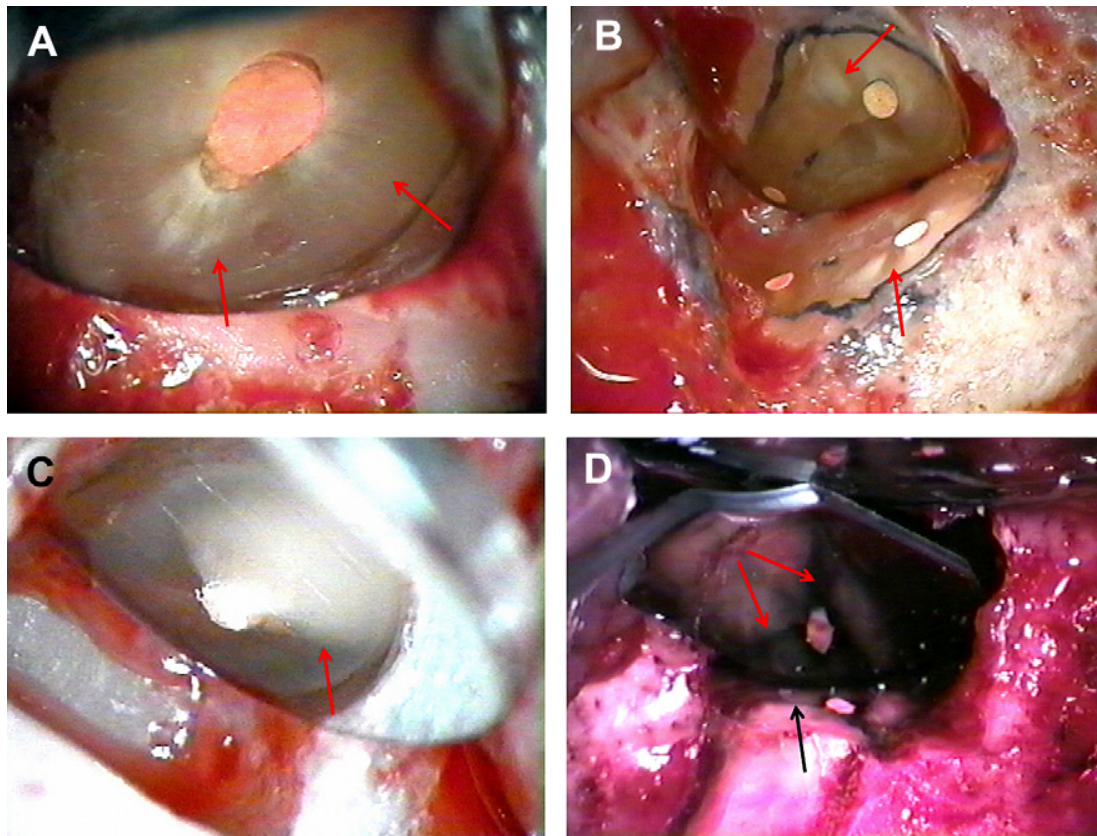


Fig. 15. (A, B) The radial dentin pattern in an anterior and posterior tooth, respectively. (C, D) The bow-tie effect. (C) The dentinal tubules of the transitional lines as they appear naturally; (D) the tubules stained at the transitional line angles from a coronally leaking obturation.

The remainder of the crypt is curetted to remove any remnants of soft tissue, sufficient hemostasis is either maintained or attained (explained in the following section), and the resected root end is disclosed with methylene blue, caries indicator, or other nontoxic dye. Subsequent observations of the root end(s) with a micromirror are made to assess the conditions of the site: are there incomplete resections, indicated by an irregular periodontal ligament perimeter or “dog-eared” projection of dentin? Are there extra roots/canals present, evident by the staining or lack of it? Are there fractures or isthmuses, and what is their location and extent? All of these points need to be cataloged and resolved before any root end preparation. One interesting observation can be made without the aid of any disclosing solution. The author terms this the “Bow-Tie” effect, and it is readily evident on the wet, resected surface of the root (**Fig. 15**). These faint lines are not fractures, but represent the transitional line angles of the root dentin/tubules. Because the dentinal tubules refract light differently, depending on their orientation to the light source, they will present a different appearance when viewed with incident

Box 1

Water prism fluid effect

Movie 9 shows the prism effect of a clear fluid in the crypt of tooth #24. With the proper fluid level, it is possible to view the resected surface without the micromirror. Without altering the position of the DOM, the fluid is removed to reveal how much of the light and view was being “bent” by the prism effect of the fluid.

Box 2**Ferric sulfate hemostasis technique**

Movie 10. Placement of a pellet moistened with ferric sulfate into this grossly bleeding crypt. Note the immediate blackening of the occult blood and pellet. The end of the video shows a curette creating a fresh bleeding surface, and sloughing of the necrotized tissue.

light. This appearance is the apical manifestation of what the author has termed “radial dentin” seen in the coronal chambers of dystrophically obliterated teeth.³⁵ This “radial dentin” tracks back to the obliterated pulp space, serving as a map to the narrowed canal. The radial dentin, apically, will point to the central location of the canal space and isthmus. This indication is especially important if the dye used did not disclose any canal/isthmus but the radial dentin suggests that it is present; the conclusion must then be drawn that the resection level did not cut through, and thereby expose, the canal/isthmus enough to capture the dye. The clinical decision is then made to either root end prepare according to the radial dentin outlines, or resect slightly more of the root end to reveal the suspected space(s).

One last observation “trick” involves the principle of a prism and its ability to bend light. This “water prism” is especially useful in the mandibular anterior apices, where space in the crypt is often cramped and bleeding slightly. After resection, the crypt is rinsed with sterile saline until it runs clear but, rather than suction the site dry, the saline is allowed to remain in the crypt. The level of the fluid can be adjusted through judicious suctioning with a microcannula, until the whole root end surface can be observed. Not only will this facilitate the accurate positioning of the USREP (UltraSonic Root End Preparation) tip without a micromirror, but the fluid itself offers a weak hemostatic tamponade effect (**Movie 9**; for movie description, see **Box 1**).

HEMOSTASIS

Before the USREP, the absolute hemostasis of the crypt needs to be achieved. Although the best hemostasis is achieved preoperatively with the anesthetic, a prolonged surgery or systemic conditions may tax the effectiveness of the Lidocaine 1:50,000. Most agents effect hemostasis by either by direct heme-agglutination or by triggering the natural clotting cascade of the patient. Of the two, the natural effect is preferable because it lasts for a relatively longer period of time. These agents, and their mode of action, are as follows.

Heme-Agglutination***Solutions***

Ferric sulfate or ferric subsulfate is the generic name for this agent. Depending on the concentration of the chemical, it is also known by the trade names: Astringedent (Ultradent Products Inc, UT, USA) Viscostat, Stasis (Cut-Trol Ichthys Enterprises, Mobile, AL, USA), and Monsel's.

Box 3**Hemodette hemostasis technique**

Movie 11. Placement of a blue Hemodette pellet and hemostasis after 3 minutes.

Box 4**ActCel hemostasis technique**

Movie 12. Placement of the material at the mesiobuccal (MB) apex of tooth #19. Demonstrates the material turning to a jelly, and the excess is removed. After hemostasis is achieved, the crypt is rinsed and the REF is placed.

The most efficient delivery is via small microbrushes dipped into a dampen dish containing the solution, and then the moist tips are discretely applied to any small bleeding points. The agglutinated proteins coagulate and form a physical plug almost immediately, and hemostasis is preserved so long as this plug remains undisturbed. Although extremely effective, all remnants of the ferric sulfate must be removed, and a fresh bleeding surface reestablished (**Movie 10**; for movie description, see **Box 2**). Otherwise, significant and adverse effects on the osseous and soft tissue healing of the site can be expected.^{36,37} The necrotizing effects, along with the difficulty in controlling the distribution and complete elimination of this agent, strongly preclude its selection in areas of neurovascular concern, namely, mandibular nerve, mental foramen, maxillary sinus, and floor of the nose.

Gels

Hemodette (20% buffered aluminum chloride gel, DUX Dental, Oxnard, CA, USA) is a water-soluble agent with agglutination properties similar to ferric sulfate, but without the deleterious side effects. This agent is packaged as 2 impregnated cotton pellets with an excess of gel in a sterile container resembling a prophyl cup. Delivery is with the cotton pellet or, using a microbrush, painting the crypt with the free gel. In addition to the heme-agglutination effect, the gel itself forms a sort of passive barrier to any minor bleeder. The blue color makes it readily identifiable in the site, and it is easily rinsed from the crypt with saline at the conclusion of the procedure (**Movie 11**; for movie description, see **Box 3**).

There are other gauze-based products such as ActCel (ActSys, Westlake Village, CA, USA), HemCon (HemCon Medical Technologies, Portland, OR, USA), and Blood-Stop (LifeSciencePlus, Palo Alto, CA, USA) that, when moistened with saline or blood from the site, break down into a gel matrix, exerting the same combination of mild tamponade and heme-agglutination as the Hemodette, and that are just as easily removed. (**Movie 12**; for movie description, see **Box 4**).

Physiologic Clotting Agents

These products are, by and large, either bovine or porcine derived connective tissue matrices that initiate the patient's own clotting cascade at the site. The advantage of this type of hemostasis is that it is usually longer lasting and more predictable in effect. Although Avitene (Avitene microfibrillar collagen hemostat, Davol Inc, Warwick, RI, USA) is the most effective and well known of this category, it is difficult to place and expensive (**Movie 13**; for movie description, see **Box 5**). A reasonable substitute would

Box 5**Avitene hemostasis technique**

Movie 13. Placement of the microfibrillar type, and the exceptional hemostasis after 2 minutes in situ.

Box 6**Colla Plug hemostasis technique**

Movie 14. Placement of a small Colla Plug disc shows adequate hemostasis after 2 minutes.

be either CollaPlug or CollaTape (Zimmer Dental, Carlsbad, CA, USA). The tape dressing can be easily cut to fit the osteotomy, and the plug can be sliced into small discs and placed over the bleeding sites. Gentle tamponade will accelerate the effect, although once the material is removed, the clotting effect will deteriorate within a few minutes (**Movie 14**; for movie description, see **Box 6**).

ROOT END PREPARATION

Since their introduction by Carr in the early 1990s, the use of the USREP tip has refined the technique and practice of this phase of the surgery. USREP tips have evolved from smooth stainless steel tips of limited configurations to a myriad of multiple bends and angles, with coatings of diamond or zirconium nitride (**Fig. 16**). The safety, efficiency, and directions for use have been well investigated in the literature, and are considered the standard for root end preparations.^{38–42} There are several manufacturers of these

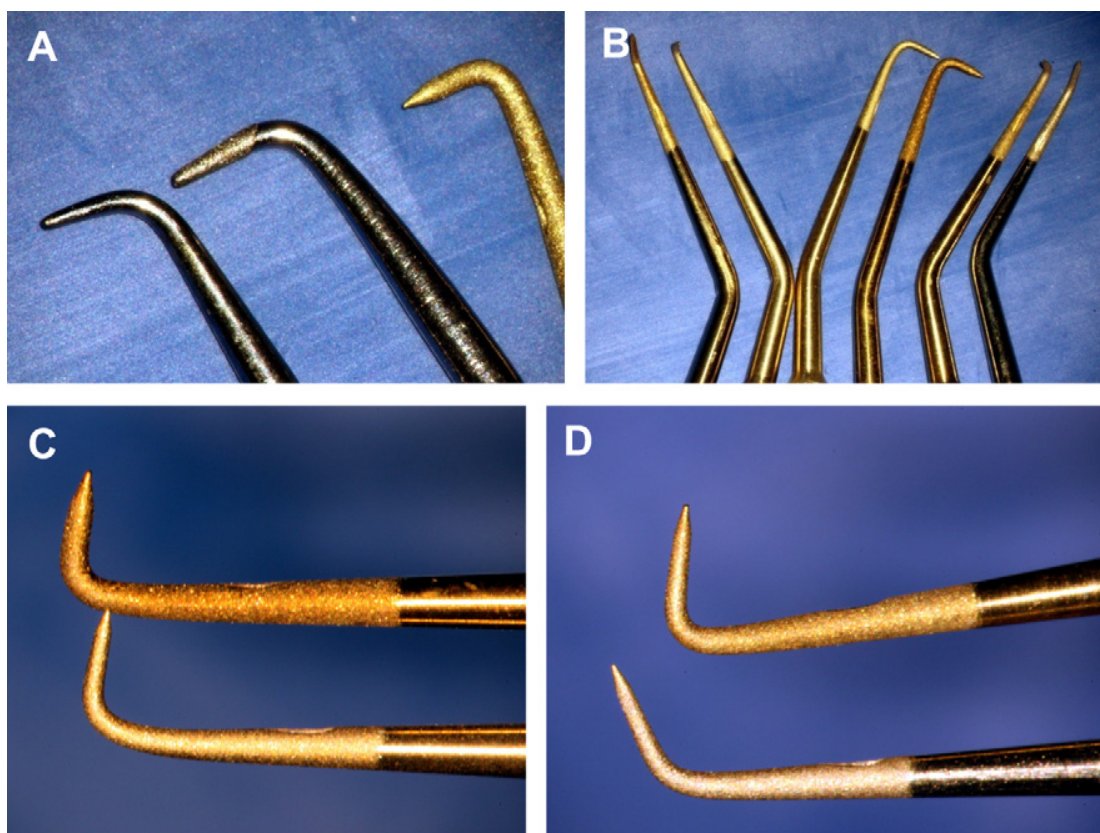


Fig. 16. USREP tips. (A, left to right) A stainless steel tip, a diamond-coated tip, and a zirconium nitride (ZN)-coated tip. (B) the assorted tip configurations for the ZN (ProUltraSurgical tips, Dentsply-Tulsa Dental, Tulsa, OK, USA). (C) The tip diameter of the smaller #1 universal tip, and the larger #2 universal tip. (D) The different tip angles of the #3 and #4 posterior surgical tips. These different angles can accommodate different surgical presentation angles of the root end without having to affect awkward handpiece positions.

Box 7
USREP tip guide

Movie 15. A reference notch is made on the cortical plate of tooth #14 MB root with the side of the US tip. This notch, made parallel to the long axis of the root at the resection site, serves as a visual reference during root end preparation to maintain the proper angle of the USREP tip.

specialized tips, and most are interchangeable with regard to the attachment to a generating unit.

TECHNIQUE

Although the universal tips are designed for anterior teeth, and tri-angled tips for posterior locations, there is no rule as to where a particular tip can or cannot be used; the determining factor is access with the selected tip attached, and visibility during its use. In single canal roots, the tip is placed into the center of the gutta percha, if present, or the center of the canal space. The tip is energized, with enough coolant delivered through the tip to cool and flush the preparation site. The tip is allowed to passively seek its way down the canal, and this will happen readily if gutta percha is in the canal. Any high-pitched squeal from the tip indicates either binding in a small, uninstrumented canal, or that the tip is traversing off-angle. Visual inspection with a micromirror is prudent at this point to ensure that the preparation is remaining centered in the canal. A groove in the buccal cortical plate, placed with the side of the USREP tip, and parallel to the long axis of the root, will also aid in the correct angulation of the preparation, especially at higher magnifications (**Movie 15**; for movie description, see **Box 7**). The preparation is complete when the full depth of the tip is reached, usually 3 mm. In a root with multiple canals and an isthmus joining them (ie, the MB root of the maxillary first molar), the 2 canals (MB1 and MB2) are prepared separately to establish the correct angulation of the preparation, then the isthmus connecting them is prepped at the same angle (**Movie 16**; for movie description, see **Box 8**). This action can be performed either directly or after tracing a small groove in the isthmus with the USREP tip dry. This latter procedure creates a trough that will be easier to replicate once the tip is activated with coolant streaming into the site, but caution should be exercised not to overheat the tip or the root end by prolonged dry cutting. These coated tips are most efficient when they are new; for that reason, it is the author's opinion that they should be considered a single-use item.

The identification and preparation of the isthmus is crucial to the sealing, and subsequent successful healing, of the root end. Although some have designated 5 or 6 types of isthmuses, they are actually permutations, based on the level of resection in a particular root, of 2 basic types: partial and complete. First identified as a prominent surgical

Box 8
USREP technique

Movie 16 shows the preparation, using a new USREP tip, of the MB root of tooth #3. The MB1 and MB2 canals are prepared first, then the isthmus is prepared maintaining the identical angle between the 2 main canals. The preparation is viewed at completion in the micromirror.

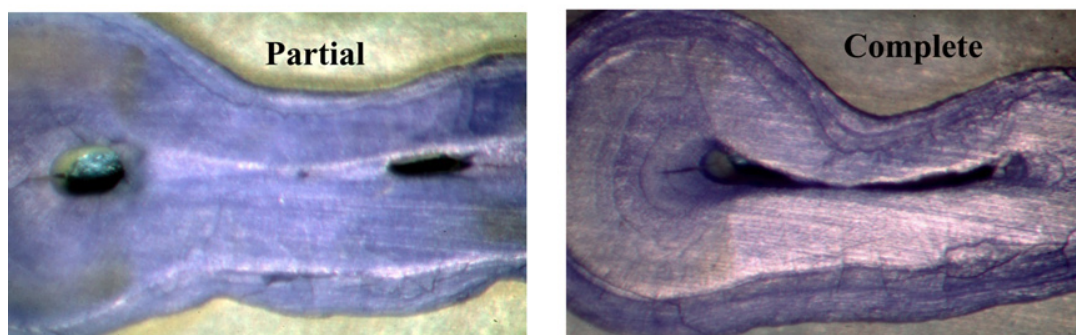
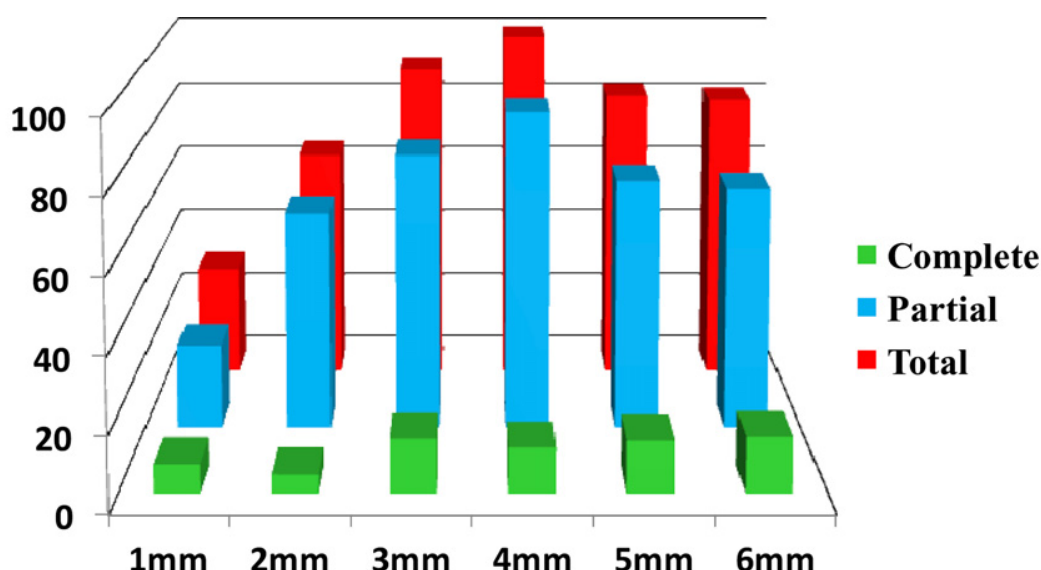


Fig. 17. In the MB root of a maxillary first molar with 2 canals, the table demonstrates an isthmus at the ideal resection length (3–4 mm) 100% of the time. (Data from Weller RN, Niemczyk SP, Kim S. Incidence and position of the canal isthmus. Part 1. Mesiobuccal root of the maxillary first molar. J Endod 1995;21:380–3.)

consideration in the MB root of a maxillary first molar (**Fig. 17**),⁴³ it has evolved to include any root that has the potential to contain 2 or more canals,^{44,45} and should be considered present until judged otherwise.

ROOT END FILLING

Although every restorative material has been used, at one time or another, as a REF, selection of today's REF is predicated on whether it is contained within a root end preparation (REP) or not. For situations whereby a REP can be created, the material of choice is Mineral Trioxide Aggregate (MTA) (ProRoot MTA, Dentsply-Tulsa Dental, Tulsa, OK, USA). This compound is easy to mix, not cumbersome to place, and extremely biocompatible.^{46–53} MTA is manufactured in white and gray formulations virtually identical in composition. The only caveat is that the material must be placed

Box 9

MAPS root end filling technique

Movie 17. Placement of MTA using a MAPS syringe. MTA is overfilled, the excess compacted with the back of a Molt curette, and the surface of the MTA dried and wiped to contour with a microbrush. Micromirror view shows 2 canals in this buccal root of tooth #12.

Box 10

MTA air-dry technique

Movie 18. The soft excess MTA is dried with an indirect airstream from the Stropko Irrigator tip. Once dried, the MTA is condensed with a ball burnisher and the excess is removed with a microbrush. The crypt is flushed with saline, and examined with a micromirror.

in a dry prep; excessive bleeding or moisture will wash the material away before setting. The most effective method to dry the REP is with a microtip attached to a Stropko Irrigator (J Bar B Co, Carefree, AZ, USA) syringe attachment. This device replaces the disposable tip of the triplex syringe, and the luer-lock end permits any size luer-lock needle tip or cannula to be readily attached. With the air pressure reduced to 3 to 5 psi, this device can direct a concentrated stream of air or water to the REP, either rinsing or drying it.

Placement of the MTA can be accomplished with a variety of instruments, from an inexpensive wipe-on block (Lee Endo Bloc, San Francisco, CA, USA) to a more sophisticated and costly syringe system (MAPS Roydent, Johnson City, TN, USA). (Movie 17; for movie description, see Box 9). Once the MTA is placed, a gentle stream of air from the Stropko is directed across the top of the REF to desiccate, and thereby firm or “skin” the exposed surface of the material. After 20 to 30 seconds, the surface of the REF is firm enough to carve and any excess can be gently wiped away with a microbrush (Movie 18; for movie description, see Box 10). The crypt may even be rinsed gently, provided the irrigant stream is not directed at the REF.

In instances whereby the depth of a post precludes a normal REP, then a bonded restoration such as Geristore (DenMat, Santa Maria, CA, USA) may be placed to seal the root end. The technique of using bonded restorations on unprepared root ends was introduced by Rud and colleagues,^{54–57} and has enjoyed a great measure of success. However, as with the MTA, it is technique sensitive with respect to moisture, and the osteotomy is often enlarged to create a “high and dry” exposure of the

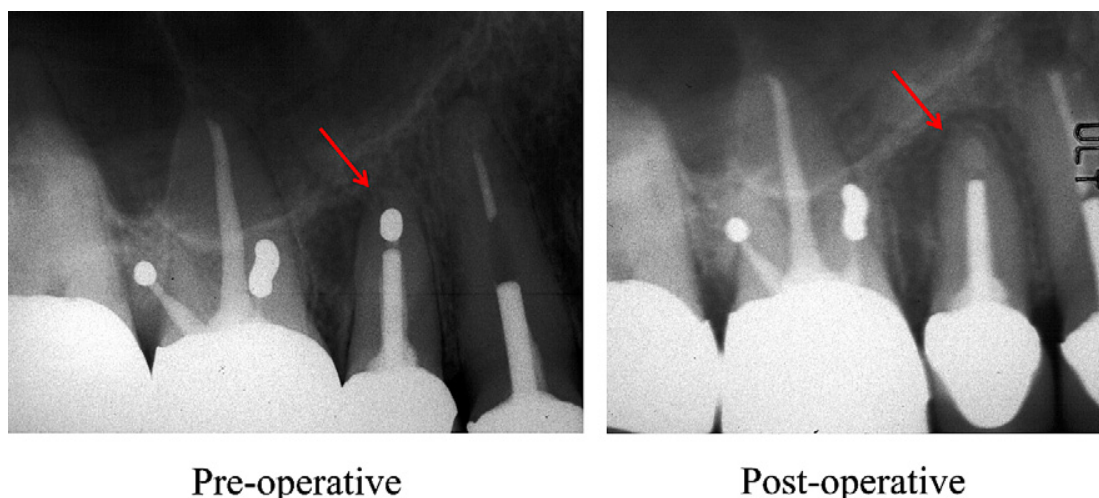


Fig. 18. Preoperative radiograph of tooth #4 reveals a post placed nearly to the root apex, and a failing retrograde in place (arrow). A bonded restoration (Geristore) replaces the amalgam and is the REF of choice when a REP of conventional depth cannot be achieved. The postoperative radiograph reveals the faint radio-opacity of the REF, and the conventional surgery and REF on tooth #5.

Box 11**Geristore root end filling technique**

Movie 19. Placement of Geristore in the apex of tooth #4. Note the close proximity of the post to the restoration.

root end. After saucering the root end, it is isolated, etched, and primed. The Geristore is a dual-cure material, so an orange filter should be placed between the DOM light source and the surgical site to prevent premature curing of the material. The REF is either troweled or syringed onto the root end, the filter removed, and the material cured with the appropriate light source, then contoured to the root outline (**Fig. 18**) (**Movie 19**; for movie description, see **Box 11**).

SUTURING/CLOSURE

After the site has been cleansed of all debris, the underside of the flap(s) is gently rinsed with sterile saline and coapted back to the original positions. A moistened gauze is placed over the coapted tissue, and gentle pressure is applied for approximately 5 minutes. This procedure effectively expresses any occult blood under the flap, and initiates a preliminary attachment of the tissues. The flap is secured with either interrupted or sling sutures; the choice of type and size is dictated by the flap design and retention requirements. Postoperative instructions should include diet and hygiene restrictions, pain medication guidelines and, most importantly, chilling of the overlying facial surface with ice (preferably in a zip-lock bag wrapped with a moist washcloth). The application of cold controls the amount of swelling from the rebound vasodilatation phase, and therefore reduces the postoperative potential for discomfort from swelling. Chilling should continue for the first 24 hours postoperatively (10–15 minutes on, 5 minutes off) except while sleeping. Suture removal, in uncomplicated cases, is normally 1 to 3 days after the operation.

SUMMARY

Today, endodontic surgeons are able to render a level of service with confidence and great precision that 20 years ago would have seemed unattainable by any standard. The development of a sophisticated armamentarium, groundbreaking techniques, and the willingness to embrace them is the future of the specialty. The next 20 years should eclipse anything previously dreamt of, if the last 20 are any barometer of things to come.

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